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UPPER-ATMOSPHERE ROTATION RATE DETERMINED FROM THE ORBIT OF CHI--ETC(U)

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ROYAL AIRCRAFT ESTABLISHMENT

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Technical Report 79115

September 1979

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**UPPER-ATMOSPHERE ROTATION RATE
DETERMINED FROM THE ORBIT OF
CHINA 6 ROCKET (1976-87B)**

by

H. Hiller

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Procurement Executive, Ministry of Defence
Farnborough, Hants

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SUMMARY

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The orbit of China 6 rocket, 1976-87B, has been determined at 51 epochs during its 17-month life, using the RAE orbit refinement computer program, PROP 6, with over 4000 radar and optical observations from 49 stations. The orbital accuracy is about 100 metres, radial and cross-track, on average.

The rotation rate of the upper atmosphere, Λ rev/day, for the height-band 200-230 km, was calculated from the decrease in orbital inclination (after being cleared of perturbations) to give the following results:

- (1) for morning conditions, $\Lambda = 0.9$ for May-June and August-September 1977, at 215 km mean height; $\Lambda = 0.7$ for October-November 1977, at 210 km; $\Lambda = 0.8 \pm 0.05$ for January-February 1978, at 200 km;
- (2) for evening conditions, $\Lambda = 1.2$ for July and September-October 1977, at 215 km;
- (3) for mean (morning plus evening) conditions, $\Lambda = 1.0 \pm 0.1$ between October 1976 and May 1977, at 230 km; $\Lambda = 0.8 \pm 0.1$ for December 1977-January 1978, at 215 km and mean latitude 57°S .

Values of density scale height have been obtained from the variation in perigee height, including several values during the final 16 days to decay. Comparison with CIRA 1972 values shows agreement mostly within 10 per cent.

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1 INTRODUCTION

China 6 rocket (1976-87B) was launched on 30 August 1976, and remained in orbit for about 17 months before decaying in the Earth's atmosphere on 4 February 1978. The initial orbit was: inclination 69.2 degrees, perigee height 190 km, apogee height 2150 km, eccentricity 0.129 and period 108.7 minutes. The orbit has been determined at 35 epochs from more than 1700 radar and optical observations with the RAE orbit refinement program¹, in the PROP 6 version. The highly-accurate Hewitt camera observations from Malvern were used in six of the orbital determinations. Further orbits were determined for each of the last 16 days of the life, using about 1300 observations obtained from the North American Air Defense Command (NORAD), about 50 US Navy observations and a Hewitt camera run of observations.

As the orbit contracted under the influence of air drag, it passed through 14th and 15th-order resonances, but too quickly for any harmonic coefficients to be determined with worthwhile accuracy. The main purpose here is to find the upper-atmosphere rotation rate from changes in inclination; the resonant perturbations are required to improve the accuracy of the rotation rate, which has been determined before, between and after the resonances.

Upper-atmosphere scale heights have been calculated for the height-band 200-230 km and compared with *CIRA 1972* values.

2 ORBIT DETERMINATION

2.1 Observations

Over 3600 radar and optical observations were used to determine the orbit at 51 epochs between 16 October 1976 and 4 February 1978. A further 400 observations of low elevation were not used. During the final orbit determinations, about 700 observations were rejected, leaving about 3000 observations or near 58 per orbit, on average. These included over 1100 from the US Navy Navspasur system and about 1400 from the assigned and contributing sensors of the North American Air Defense Command (NORAD) Space Detection and Tracking System (SPADATS). A further 300 were visual, from volunteer observers reporting to the Appleton Laboratory at Slough; 200 or so were from British radar; 18 from the Malvern Hewitt camera, distributed over seven orbits; 24 from Jokioinen, Finland and 15 from the kinetheodolite at the South African Astronomical Observatory.

2.2 Observational accuracy

Table 1

Residuals for selected stations

Station		Number of observations	Rms residuals			
			Range km	Minutes of arc		
				RA	Dec	Total
1	US Navy	84	0.8*	1.8	2.4	2.9
2	US Navy	33		2.3	2.1	3.2
3	US Navy	42		2.0	1.7	2.6
4	US Navy	51		1.6	2.1	2.7
5	US Navy	95		2.0	2.2	3.0
6	US Navy	110		1.8	2.4	3.0
29	US Navy	693		0.5*	0.5*	
414	Capetown	10		2.3	3.0	3.8
2122	Malvern 5	27		1.7	1.9	2.5
2155	Bahrein 2	17		1.6	3.1	3.5
2265	Farnham	29		2.0	2.2	3.0
2303	Malvern Hewitt camera	18		0.04	0.08	0.09
2414	Bournemouth	103		3.2	3.8	4.9
2420	Willowbrae	119		2.1	2.1	3.0
2577	Cape kinetheodolite	15		0.6	0.5	0.8
6702	Jokioinen	24		3.5	2.7	4.4

* Geocentric

Table 1 lists the observing stations which have contributed at least 10 observations to the determination of the first 35 orbits. The observational accuracy of these stations is given in the form of rms residuals, obtained from the RAE computer program ORES². The Hewitt camera observations have the highest accuracy, with about 5 seconds of arc; the US Navy stations have topocentric accuracies near 3.0 minutes of arc; the Jokioinen theodolite 4.4 minutes of arc; the Cape kinetheodolite, 0.8 minutes of arc. The stations with visual observers reporting to the Appleton Laboratory at Slough, have residuals between 2.5 and 4.9 minutes of arc. Each observer has been sent a list of his own residuals.

2.3 Orbital accuracy

The computed sets of orbital elements at 51 epochs between October 1976 and February 1978 are shown in Table 2, with standard deviations where appropriate. The sd in inclination varies from 0.0005 to 0.0028°, with an rms of 0.0015°. For the final 16 daily orbits, the sd varies from 0.0005 to 0.0010°, with an rms of 0.0007°. For eccentricity, plotted in Fig 1, the rms for the 51 values of sd is 2×10^{-5} , but only 1×10^{-5} (equivalent to 70 m in perigee height) for the

final 16 values. For argument of perigee, ω , or mean anomaly at epoch, M_0 , the (similar) sd varies from 0.005 to 0.090°. The values of orbital decay rate, M_2 , plotted in Fig 2, have sd varying from 0.0002 to 0.003 deg/day² for the first 35 orbits; but for the final 16 orbits (approaching decay), shown in the inset on Fig 2, the sd increases and on the actual decay day, $M_2 = 30.71 \pm 0.05$ deg/day².

3 VARIATION IN PERIGEE HEIGHT

It is useful to analyse the perigee height first, because the results are used in deciding the height at which the rotation rate applies (see section 6).

The values of semi major axis, a , and eccentricity, e , given in Table 2, were used to calculate perigee height over a spherical Earth, h_p , from

$$h_p = a(1 - e) - R, \quad (1)$$

where R is the Earth's equatorial radius, taken as 6378.14 km. The values, cleared of perturbations, are plotted in Fig 3, up to MJD 43524, as crosses. The main oscillation is due to the odd-harmonic perturbation in e , which, combined with the lunisolar perturbation, was calculated using the PROD program³, to give a total perturbation Δe . A parameter Q , the perigee height over a spherical Earth, cleared of perturbations, can now be determined from

$$Q = h_p + a\Delta e,$$

and the values obtained are shown in Fig 3 by triangles. The perturbation Δe is assumed to be zero initially, so that the Q values are relative (rather than absolute). This is not significant here, since only the slope dQ/dt is used (in section 4) for calculating density scale height.

The values of h_p and Q in the final 16 days before satellite decay are plotted in Fig 4 (which is an extension of Fig 3).

4 DENSITY SCALE HEIGHT

The density scale height H is a measure of the rate of decrease of density ρ as height y increases, and is defined by $\frac{1}{H} = -\frac{1}{\rho} \frac{d\rho}{dy}$. Values of H were calculated from \dot{Q} , the rate of change of Q due to air drag, where⁴, for $ae/H > 3$,

$$\dot{Q} = -\frac{2HM_2}{3M_1e} \left(1 - 2e + \frac{H}{4ae} - \frac{2\epsilon'}{e} \sin^2 i \cos 2\omega \right), \quad (2)$$

ϵ' is the ellipticity of the atmosphere ($=0.00335$) and H is at a height $1.5 H_p$ above the satellite's perigee height y_p . The other variables are defined in Table 2. Ignoring small perturbations, we may take y_p as given by the right-hand side of equation (1) with R replaced by the local Earth radius at perigee latitude. For 1976-87B, at 69° inclination,

$$y_p = h_p + 18.67 \sin^2 \omega.$$

Values of \dot{Q} for use in equation (2) are obtained in the form $\Delta Q/\Delta t$, from the change ΔQ in Q over a suitable time interval Δt . Since Q has an accuracy of about 0.2 km, values of ΔQ of 3 km or more are required to give values of \dot{Q} accurate to 5 per cent, and the time intervals were chosen on this basis. Values of H were obtained from equation (2) using these values of \dot{Q} and mean values of the other parameters. The values of H are plotted against time span in Fig 5, as circles with sd, up to MJD 43540. At this point, $ae/H \approx 3$.

For the final three (daily) calculations of H , the value of ae/H was less than 3. The 'phase 2' regime discussed in Ref 5 (page 88) can then be used: equation (5.35) of Ref 5 gives

$$\frac{da}{dx} = y_0 + \frac{1}{2}e(4 - 3y_0^2 - y_0y_2) - \frac{1}{2}c \cos 2\omega(y_0 - 2y_2 + y_0y_3) = \beta, \text{ say} \quad (3)$$

where $c = \frac{\epsilon'a(1-e)}{2H} \sin^2 i$, $y_r = I_r/I_1$, and I_r is the Bessel function of the first kind and imaginary argument, of order r (*ibid*, page 36).

To calculate H from \dot{Q} , put

$$\dot{Q} = \frac{dQ}{da} \cdot \frac{da}{dt} = -\frac{d(a-x)}{da} \cdot \frac{2\dot{n}a}{3n},$$

where $n(=M_1)$ is the mean motion and $\dot{n} = 2M_2$. Hence

$$\frac{da}{dx} = 1/(1 + 3M_1\dot{Q}/4M_2a) = \alpha, \text{ say.} \quad (4)$$

H is now determined by selecting two likely values, H_1 and H_2 , which are used to calculate β_1 and β_2 from equation (3), and then by linear interpolation from

$$H = \frac{H_1(\beta_2 - \alpha) + H_2(\alpha - \beta_1)}{\beta_2 - \beta_1} . \quad (5)$$

These three values of H are included in Fig 5 as circles, with sd, for $43540 \leq \text{MJD} \leq 43543$. The sd for all the H values shown have been estimated from the errors in perigee height (usually 0.2 km). The height y_1 at which H applies has been plotted in Fig 5; also the 10.7 cm solar flux, $F_{10.7}$, in the form of mean monthly values up to MJD 43529, and daily thereafter.

For comparison, values of scale height H obtained⁶ from CIRA 1972, for the same heights and exospheric temperatures as the calculated values, have also been plotted in Fig 5 as crosses. These observational values of scale height, between 180 and 240 km height, are about 7 per cent rms above CIRA 1972 values for high solar activity in 1977-8. In a previous study⁷, the observational values (at similar heights) were about 10 per cent below CIRA 1972 values for lower solar activity (1972-6).

The observational density scale height H has been replotted against height in Fig 6, with comparative curves from CIRA 1972, for various exospheric temperatures. The calculated exospheric temperatures are shown in brackets after the observational values (indicated by crosses generally or by circles near decay). The calculations were made using CIRA 1972 with the appropriate values of solar 10.7 cm radiation energy and geomagnetic index, with adjustments for semi-annual variations. Again the observational values of H are higher than the values given by CIRA 1972, for the appropriate exospheric temperature, the difference being 6 per cent rms.

5 RESONANCES

5.1 14th-order

The orbit of China 6 rocket was perturbed by 14th-order resonance between May and August 1977, with exact 14th-order resonance occurring on 25 June (MJD 43319). Unfortunately there were only five PROP values of inclination during this time-span for determining lumped 14th-order geopotential coefficients; a further six US Navy values of inclination were also available - but even 11 values are insufficient to determine such coefficients accurately. However, a fitting was made to these 11 values, after removing unwanted perturbations, as

the resonance effect on inclination is required for improving the accuracy in calculating the rotation rate of the atmosphere (section 6). The perturbations to be removed were found using the computer program PROD³ and the resulting inclinations were fitted using the computer program THROE⁸ by the method described in Ref 7, using only the $(\gamma, q) = (1, 0)$ terms. The inclination change due to 14th-order resonance was found to be 0.0058° , and is shown plotted in Fig 7 as a vertical line at exact 14th-order resonance.

5.2 15th-order

The change in inclination at 29:2 resonance is too small to be worth considering, but at 15th-order resonance the orbit was perturbed sufficiently to warrant an estimation of an allowance to be made in the inclination fitting of Fig 7. The resonant perturbation is, however, too rapid for the determination of lumped geopotential coefficients. It occurred between October and December 1977, with exact 15th-order resonance on 25 November.

There were only seven PROP and two US Navy values of inclination available and the fitting was made using $(\gamma, q) = (1, 0)(1, \pm 1)$. The overall change in inclination due to 15th-order resonance was 0.0022° and is plotted in Fig 7 as a vertical line at exact 15th-order resonance (MJD 43472). The method of fitting is as described in Ref 7.

6 ATMOSPHERIC ROTATION RATE

The 51 derived values of inclination, given in Table 2, were cleared of lunisolar and geopotential perturbations using the PROD program³ with numerical integration at one-day intervals. These modified values are plotted in Fig 7. The change in inclination was then calculated for several values of atmospheric rotation rate (expressed as Λ times the Earth's rotation rate, in rev/day), using oblate-atmosphere theory⁹, with numerical integration at about 20-day intervals (corresponding to 22.5° steps in argument of perigee, ω). For the final 16 days of the orbit, however, the intervals were reduced to 1 day.

For the first 7 months, MJD 43067-43282, the local time at perigee (see scale at top of Fig 7) passed through morning and evening at least twice each, so the value of Λ obtained is an average one and is given by $\Lambda = 1.0 \pm 0.1$ rev/day for a mean height of $\bar{y}(= \bar{y}_p + 0.75H) = 228$ km.

In the last 16 days, where there are daily orbits, the values of i , which have been replotted with greater accuracy in Fig 8, are fitted most satisfactorily by $\Lambda = 0.8 \pm 0.05$ rev/day for morning conditions (local time 01-06 h),

at a mean height of 200 km. This implies an east-to-west wind of 80 ± 40 m/s. The effect of meridional winds, μ rev/day, is expected to be small, as the orbital inclination is high; however, a value of $\mu = 0.2$ (south-to-north) added to the $\Lambda = 0.8$ curve, has been calculated and plotted in Fig 8 (broken line) to show its effect. The average meridional wind at local time 01-06 h is expected¹⁰ to be about 40 m/s south-to-north in Southern latitudes, equivalent to $\mu = 0.08$; the fit is not improved by the inclusion of μ . Also $\mu = 0.08$ would have about the same effect as an increase of 0.03 in Λ . Any errors due to neglect of μ can therefore be absorbed in the error of 0.05 in Λ .

In the intermediate months, for MJD 43282-43528, the values of i could not be fitted satisfactorily by a mean Λ -curve, and so the region was subdivided into morning (02-14 h) and evening (14-02 h) sections. Although the normal time division¹¹ is 04-12 h for morning and 16-24 h for evening, it was expedient here to divide the day into two, rather than four, parts. The numerical integration was repeated with further dates, at which the local time at perigee was 02 h and 14 h, added to the original set of dates. The Λ -fittings were made to each section separately, including inclination 'jumps' at 14th- and 15th-order resonances, as shown in Fig 7. The 'morning' sections are shown as broken lines, the 'evening' as unbroken. The fittings are now acceptable and give the following values for Λ in rev/day:

- (1) MJD 43282-329, $\Lambda = 0.9$, for morning conditions, at a mean height of 217 km, for May-June 1977
- (2) MJD 43329-364, $\Lambda = 1.2$, evening, at 214 km, for July 1977
- (3) MJD 43364-398, $\Lambda = 0.9$, morning, at 215 km, for August-September 1977
- (4) MJD 43398-440, $\Lambda = 1.2$, evening, at 215 km, for September-October 1977
- (5) MJD 43440-482, $\Lambda = 0.7$, morning, at 210 km, for October-November 1977
- (6) MJD 43482-528, $\Lambda = 0.8 \pm 0.1$, mean (dotted), at 217 km, for December 1977-January 1978.

The sd in Λ for (1) to (5), between May and November 1977, are not given, as there are insufficient inclination values to determine them individually (see Fig 7). However, an overall sd has been determined using the THROE program⁸, by a fitting to all the inclination values and then finding the change in Λ corresponding to a change in the di/dt term. The sd obtained was 0.05.

The values of Λ for (1) to (5), which indicate $\Lambda \simeq 1.2$ in the evening and between 0.7 and 0.9 in the morning, are in agreement with past results obtained from other satellites¹¹; however, (6) appears to give an anomalous result for Λ . To date, at heights below 400 km, $\Lambda < 1$ has been an indication of

morning conditions. For a height near 220 km, under mean conditions, the expected value is near $\Lambda = 1.1$, *ie* a wind speed of about 40 m/s, west-to-east. Here (6) gives $\Lambda = 0.8 \pm 0.1$, which represents a wind speed of 80 ± 40 m/s, east-to-west. However, this apparently anomalous result is in agreement with a study¹² where for similar conditions (height 215 km; mean latitude 57°S ; mid-summer; high solar activity), the wind is found to be from east-to-west (Fig 6d of Ref 12), and the near 60 m/s magnitude is in close agreement. The result also confirms the tentative conclusion¹³ from analysis of the Cosmos 462 orbit, that Λ tends to be lower in summer than in winter, and this provides a basis for further refinement in terms of season, in future analyses.

7 CONCLUSIONS

The orbit of China 6 rocket, 1976-87B, has been determined at 51 epochs between October 1976 and February 1978, including orbits determined for each of the last 16 days, up to the day of decay, on 4 February. The total number of observations available was more than 4000, and there were Hewitt camera observations on seven of the 51 orbits. The sd in inclination varied from 0.0005 to 0.0028° , while the sd in eccentricity varied between 6×10^{-6} (equivalent to 40 m in perigee height) and 3×10^{-5} .

Values of density scale height have been determined from the change in perigee height and compared with values from the CIRA 1972 reference atmosphere; the values obtained are about 7 per cent higher than CIRA, on average.

Eight values for the atmospheric rotation rate Λ , in rev/day, have been determined from the variations in inclination, for heights between 200 and 230 km, between October 1976 and February 1978. Two mean values (averaged over morning and evening) are $\Lambda = 1.0 \pm 0.1$ at 230 km and $\Lambda = 0.8 \pm 0.1$ at 215 km. The four morning values are $\Lambda = 0.8 \pm 0.05$ at 200 km; $\Lambda = 0.7$ at 210 km; $\Lambda = 0.9$ at 215 km, twice. The two evening values are $\Lambda = 1.2$ at 215 km, twice. The resonance effects on inclination at 14th- and 15th-order resonances have been accounted for, as well as lunisolar and geopotential perturbations.

Seven of the eight values of Λ agree well with values obtained from other satellites. The eighth value, $\Lambda = 0.8 \pm 0.1$, for a height of 215 km, appears to be anomalous: it is equivalent to an east-to-west wind of 80 ± 40 m/s whereas, under mean conditions, a west-to-east wind of 40 m/s was expected. The value applies, however, for December 1977-January 1978 at a mean latitude of 57°S , that is at high latitude at midsummer. The result reinforces a previous tentative conclusion¹³ that Λ is lower in summer than in winter and agrees well

with the numerical model of Ref 12, which indicates an east-to-west wind of about 60 m/s, in similar conditions (*ie* at height 215 km; mean latitude 57°S ; mid-summer and high solar activity).

Table 2
ORBITAL PARAMETERS FOR CHINA 6 ROCKET, WITH STANDARD DEVIATIONS

Orbit	Date	MJD	a	e	i	Ω	ω	M_0	M_1	M_2	M_3	M_4	ϵ	D	N
1	1976 Oct 16	43067.0	7501.269	0.12481	69.1540	359.707	90.192	336.349	4811.549	0.4631	0.0058	-0.00112	0.66	9.4	28
2	31	082.0	7488.499	0.12315	69.1532	328.537	74.108	244.706	4823.865	0.4535	0.0045	-0.00139	0.97	8.6	41
3	Nov 17	099.0	7473.544	0.12167	69.1506	293.006	55.852	290.522	4838.354	0.4476	-0.00063	0.00028	0.62	9.8	46
4	28	110.0	7462.664	0.12016	69.1493	269.889	43.949	288.340	4848.941	0.5312	-0.00351	-	0.54	9.6	27
5	Dec 10	122.0	7449.558	0.11851	69.1492	244.558	30.918	229.581	4861.746	0.6304	0.0017	-0.00104	0.50	7.5	27
6	23	135.0	7433.504	0.11653	69.1472	216.931	16.679	175.536	4877.507	0.5487	-0.00087	0.00100	0.69	9.7	49
7	1977 Jan 3	146.0	7419.829	0.11484	69.1407	193.408	4.573	260.151	4891.000	0.5615	-0.0063	0.00146	0.53	9.5	51
8	20	163.0	7400.976	0.11241	69.1425	156.798	345.684	47.649	4909.704	0.5336	-0.0015	-0.00054	0.64	9.1	50
9	Feb 3	177.0	7386.097	0.11048	69.1457	126.436	219.943	124.474	4924.551	0.5384	-0.0086	-	0.67	9.0	57
10	17	191.0	7371.224	0.10844	69.1421	95.879	314.122	50.506	4939.465	0.5459	-0.0008	-0.00038	0.63	8.5	47
11	26	200.0	7362.135	0.10741	69.1398	76.129	303.899	267.825	4948.617	0.4842	-0.0010	-	0.62	5.8	72
12	Mar 6	208.0	7354.823	0.10650	69.1365	58.511	294.743	286.848	4956.001	0.4635	0.0072	-	0.72	8.0	73
*13	16	218.0	7344.734	0.10516	69.1385	36.405	283.225	218.489	4966.218	0.4359	-0.0049	0.00113	0.78	8.1	66
*14	24	226.0	7338.127	0.10437	69.1438	18.662	274.025	15.406	4972.929	0.4122	-	-	0.84	6.6	56
*15	30	232.0	7333.209	0.10382	69.1453	5.324	267.059	348.065	4977.933	0.3902	-0.0115	-0.00107	0.56	5.1	51
*16	Apr 4	237.0	7329.775	0.10336	69.1459	354.185	261.342	46.349	4981.433	0.4004	0.0136	-	0.80	6.2	74
17	14	247.0	7320.705	0.10240	69.1427	331.848	249.751	228.436	4990.695	0.4139	0.0008	-	0.72	9.0	48
18	May 3	266.0	7302.299	0.10021	69.1352	289.157	227.637	184.721	5009.580	0.6289	0.0047	-0.00113**	0.80	0.4	52
*19	25	288.0	7273.254	0.09706	69.1376	239.225	201.879	193.037	5039.625	0.7279	0.00036	-	0.60	9.4	45
*20	Jun 4	298.0	7258.631	0.09547	69.1311	216.315	190.098	263.255	5054.865	0.8248	-0.0010	-	0.70	7.1	43
21	13	307.0	7244.588	0.09390	69.1262	195.559	179.341	103.354	5069.572	0.8337	0.0025	-	0.77	9.0	39
22	Jul 12	336.0	7198.878	0.08859	69.1273	127.796	144.553	230.028	5117.945	0.7412	-0.0019	0.00033	0.79	10.0	27
23	Aug 9	364.0	7158.809	0.08379	69.1212	61.131	110.444	129.685	5160.984	0.8318	0.00389	0.00034	1.02	9.9	33
24	24	379.0	7134.352	0.08080	69.1230	24.889	91.844	342.715	5187.552	0.8836	0.0027	0.00020	0.78	9.3	31

** $M_5 = 0.00005 \pm 1$

Table 2 (concluded)

Orbit	Date	MJD	a	e	i	Ω	ω	M_0	M_1	M_2	M_3	M_4	c	D	N
25	1977 Oct 17	43433.0	7025.422	0.06663	59.1111	250.801	23.736	341.578	5308.698	1.7980	0.0120	-0.00158	0.19	9.1	29
26	Nov 6	453.0	6959.954	0.05789	69.1036	198.920	357.302	340.552	5383.796	2.0229	0.0179	-0.00444	0.79	8.0	59
27	13	460.0	6936.361	0.05468	69.1006	180.373	347.745	324.027	5411.294	1.9938	0.0315	-	0.58	5.6	57
28	20	467.0	6912.719	0.05157	69.0965	161.597	338.010	144.022	5439.086	1.7589	-0.0207	-	0.65	7.0	76
29	28	475.0	6889.737	0.04852	69.0941	139.892	326.86	203.04	5466.330	1.7071	-0.0345	0.00374	0.87	8.0	55
30	Dec 8	485.0	6860.741	0.04441	69.0942	112.445	312.46	320.57	5501.030	1.5064	-0.0038	0.00464**	0.69	9.0	73
31	18	495.0	6831.798	0.04053	69.0966	84.584	298.09	62.12	5536.035	1.7390	-0.0153	-0.00155	0.90	9.6	61
32	28	505.0	6804.873	0.03699	69.0962	56.350	283.26	145.28	5568.933	1.7969	0.0174	0.00045	0.78	8.7	71
33	1978 Jan 2	510.0	6789.099	0.03498	69.0946	42.089	275.79	317.55	5588.359	2.0671	0.0330	0.00453	0.74	6.2	36
34	8	516.0	6763.991	0.03161	69.0921	24.788	266.86	98.96	5619.513	2.3647	0.0246	0.01718*	0.70	6.0	43
35	16	524.0	6730.526	0.02729	69.0898	1.367	254.60	222.70	5661.488	2.6799	0.0296	0.00345	0.76	7.0	49
36	20	528.0	6712.342	0.025128	69.0896	349.532	248.29	234.28	5684.515	2.878	-	-	0.53	1.08	57
*37	21	529.0	6707.915	0.024476	69.0887	346.546	246.79	161.59	5690.146	2.944	-	-	0.53	0.70	98
38	22	530.0	6703.533	0.023962	69.0893	343.559	245.36	94.46	5695.778	2.854	-	-	0.44	0.96	84
39	23	531.0	6698.915	0.023381	69.0889	340.564	243.66	33.23	5701.620	3.067	-	-	0.37	0.90	89
40	24	532.0	6694.047	0.022789	69.0881	337.561	242.09	337.95	5707.843	3.288	-	-	0.55	1.01	93
41	25	533.0	6688.496	0.022119	69.0891	334.550	240.71	289.06	5714.952	3.855	-	-	0.51	0.95	92
42	26	534.0	6682.050	0.021293	69.0903	331.530	239.00	248.12	5723.226	4.853	0.46	-	0.50	1.12	82
43	27	535.0	6674.592	0.020251	69.0897	328.493	237.29	216.41	5732.824	4.816	0.49	-	0.46	0.64	69
44	28	536.0	6667.408	0.019519	69.0878	325.457	236.03	193.62	5742.094	4.653	-	-	0.47	1.00	85
45	29	537.0	6659.764	0.018590	69.0859	322.403	234.66	180.26	5751.987	5.783	0.15	-	0.55	0.76	70
46	30	538.0	6650.001	0.017720	69.0879	319.333	233.39	177.99	5764.662	7.025	-	-	0.58	0.83	85
47	31	539.0	6638.786	0.015998	69.0860	316.249	231.80	189.85	5779.280	7.598	-	-	0.55	0.77	82
48	Feb 1	540.0	6625.654	0.014407	69.0852	313.142	230.66	216.70	5796.475	9.776	-0.28	-	0.57	1.07	67
49	2	541.0	6610.733	0.012613	69.0845	310.019	229.54	262.38	5816.117	10.542	1.40	-	0.62	0.69	67
50	3	542.0	6592.085	0.010529	69.0830	306.857	228.67	339.39	5840.822	14.742	1.68	-	0.58	0.76	58
51	4	543.0	6581.758	0.007244	69.0776	303.665	228.37	66.51	5881.372	30.71	10.54	2.7	0.49	0.76	59

Key: MJD Modified Julian Day Ω right ascension of node (deg)
a semi-major axis (km) ω argument of perigee (deg)
e eccentricity i inclination (deg) M_0 mean anomaly at epoch (deg)
 M_1 mean motion, n (deg/day)
 M_2 additional coefficients in polynomial for M
 M_3 additional coefficients in polynomial for M
 M_4 additional coefficients in polynomial for M
 M_5 additional coefficients in polynomial for M
c measure of fit
D time coverage of observations (days)
N number of observations used

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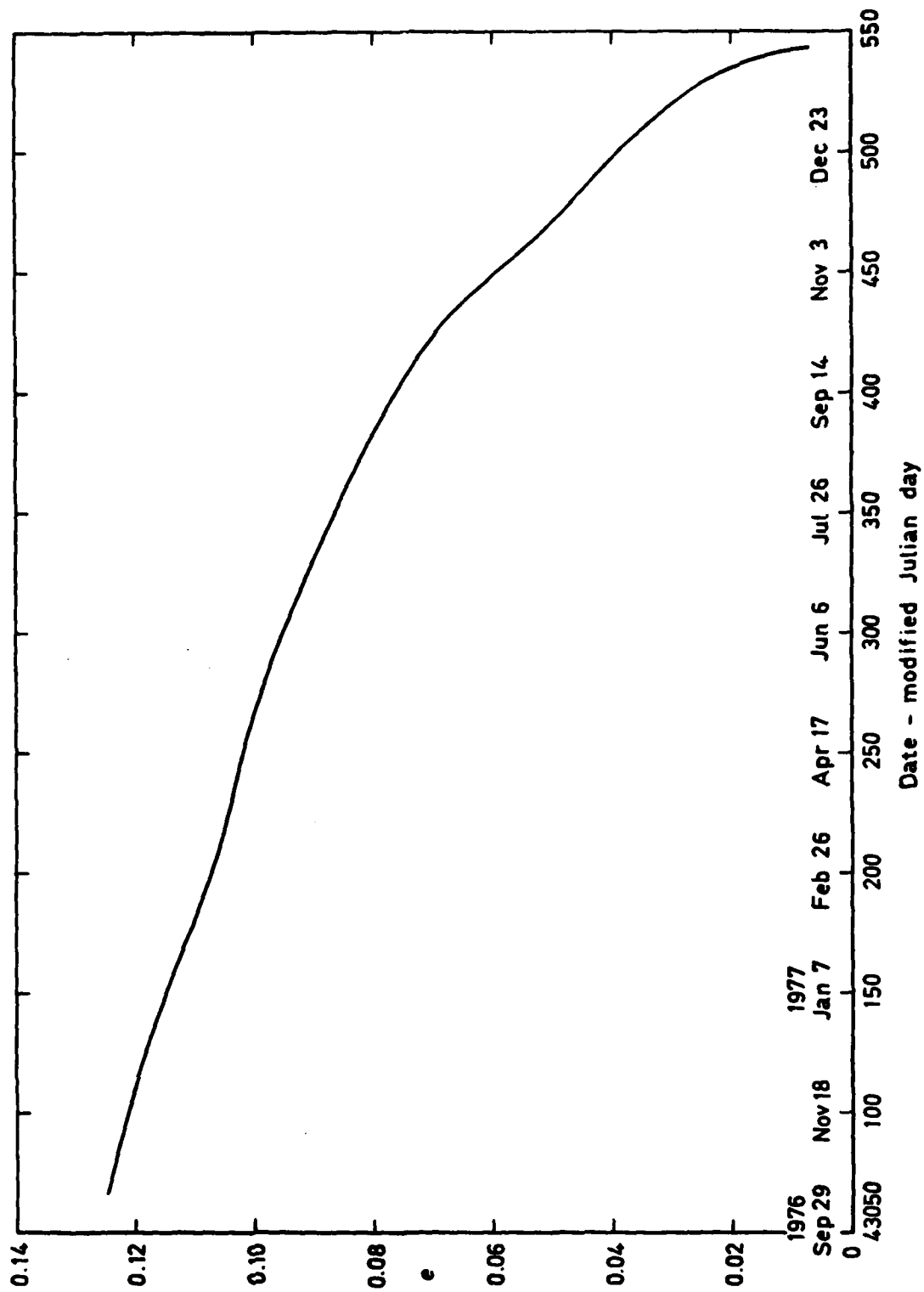
Fig 1 Observational curve of eccentricity e

Fig 2

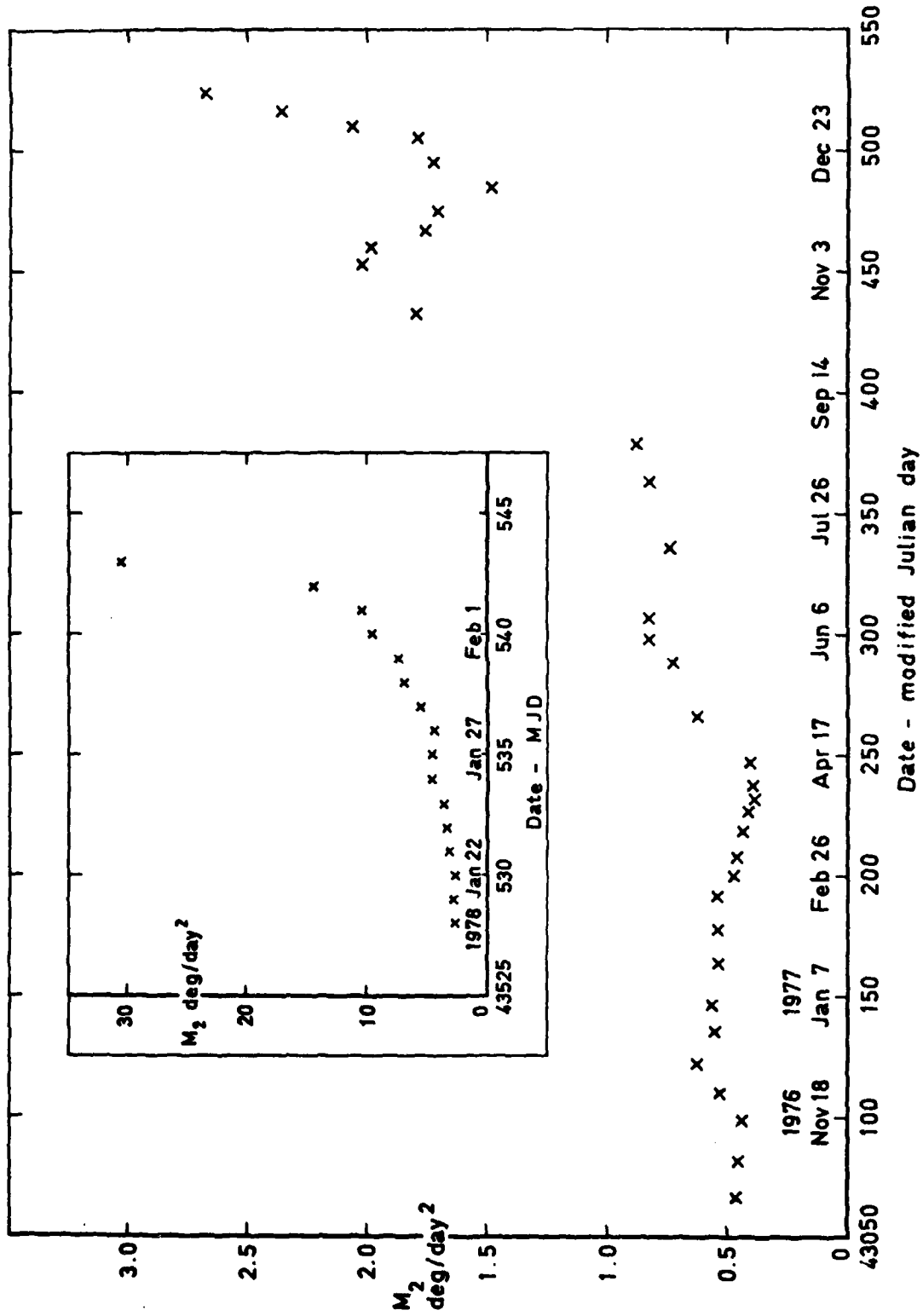


Fig 2 Observational values of orbital decay rate, M_2

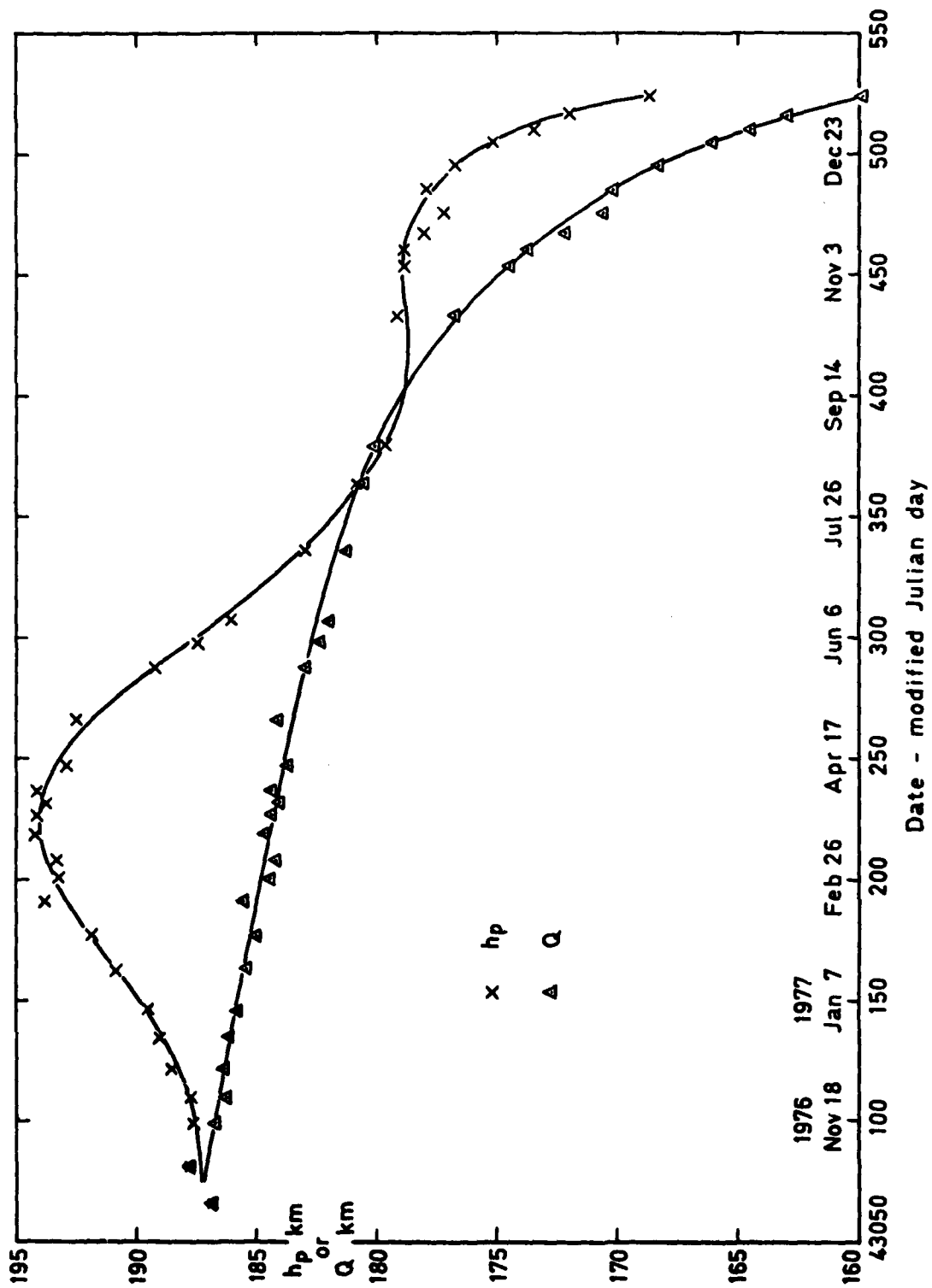


Fig 3 Perigee heights, h_p and Q (cleared of perturbations), over a spherical Earth

Fig 4

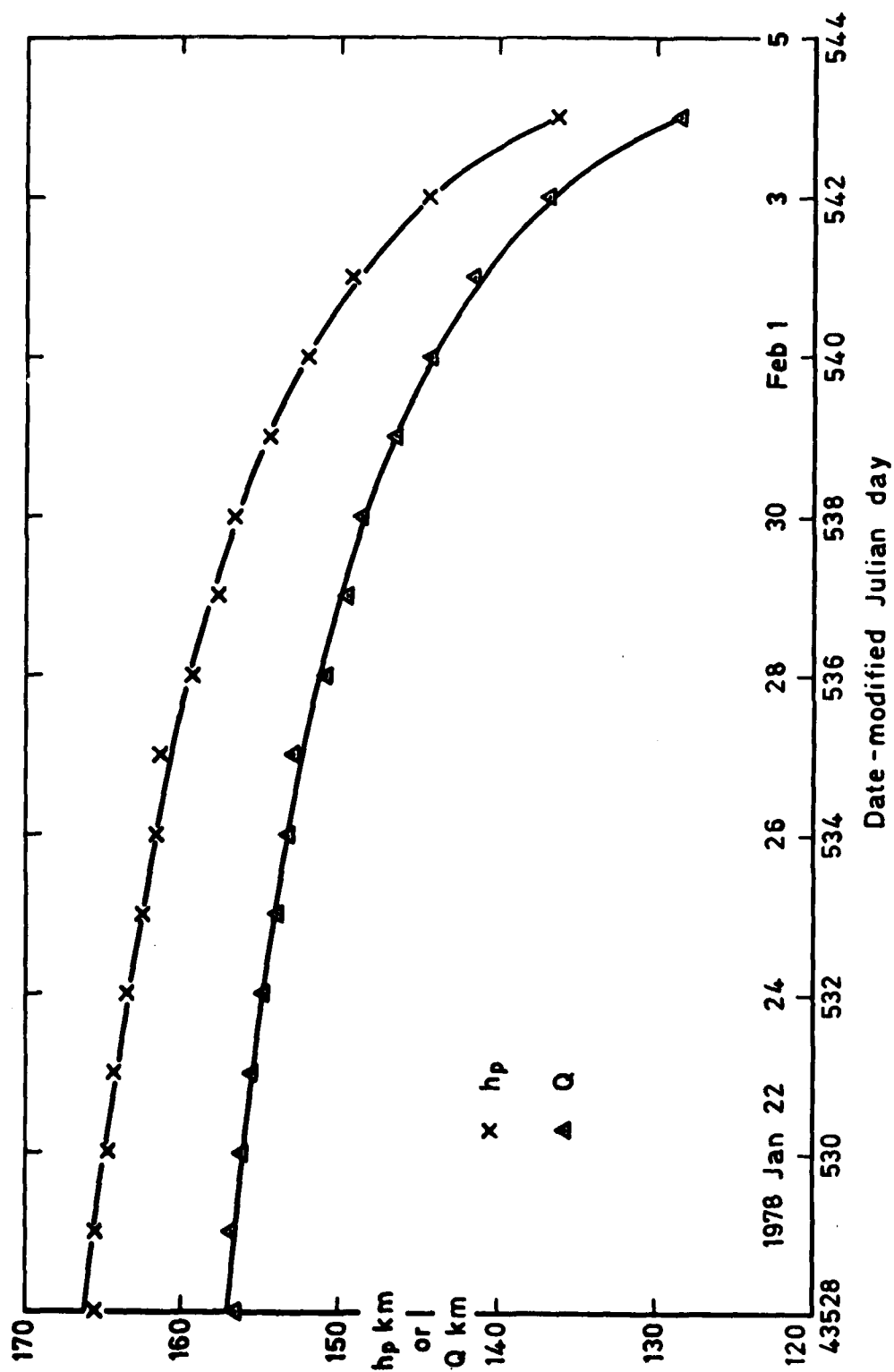


Fig 4 Perigee heights, h_p and Q (cleared of perturbations), near decay

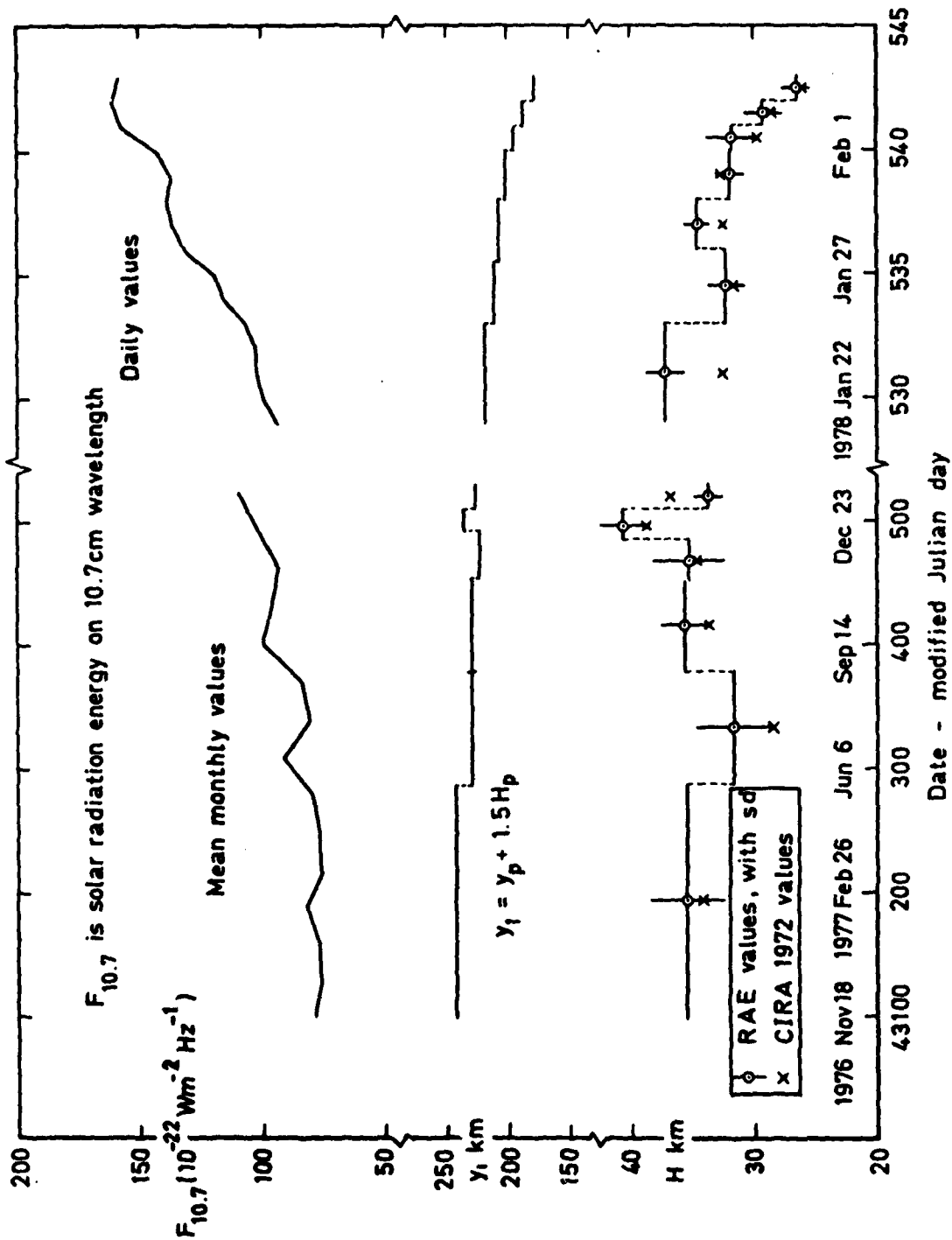


Fig 5 Variation of density scale height H at height Y_1 and variation of solar $F_{10.7}$ index

Fig 6

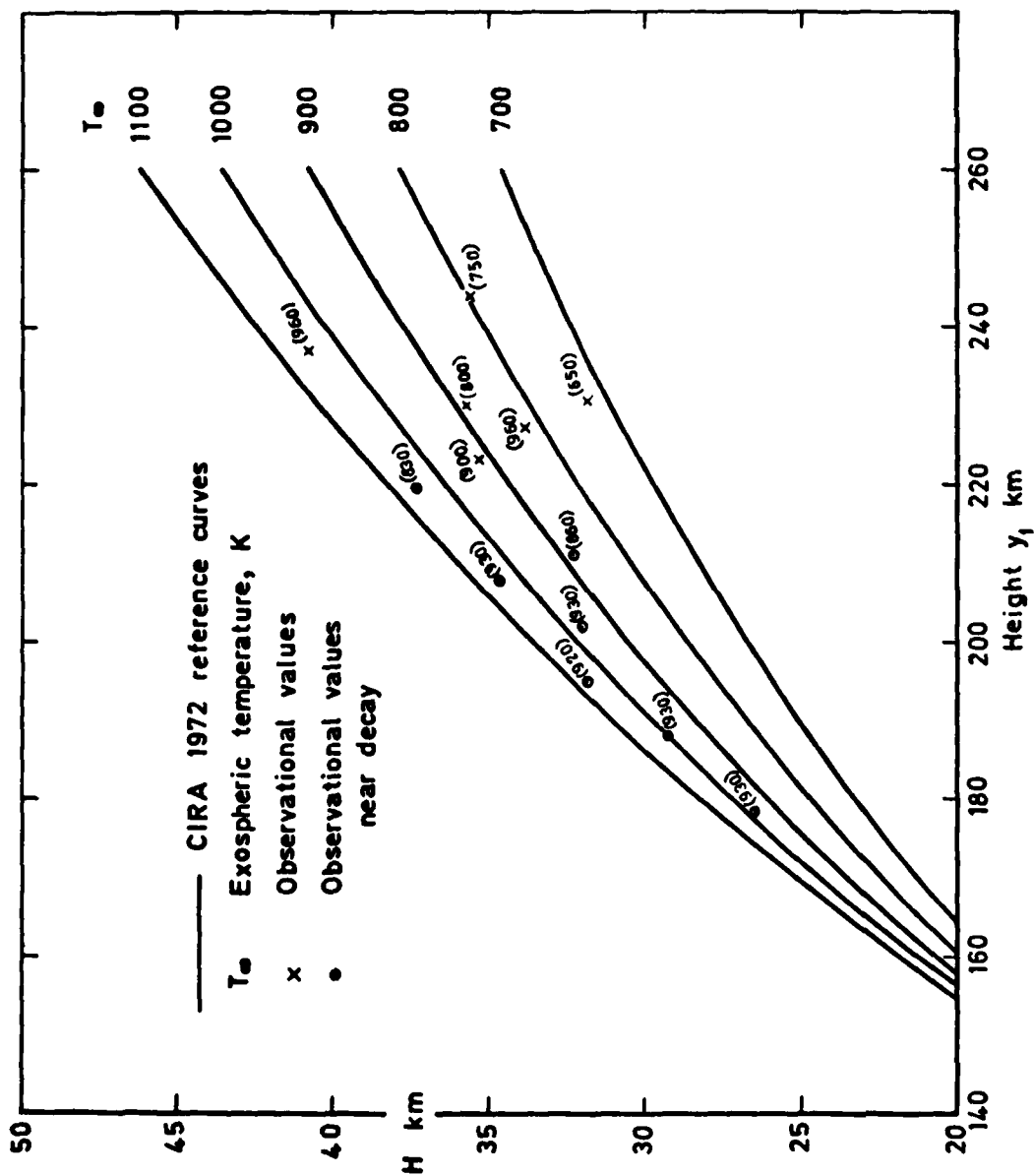


Fig 6 Density scale height, H , compared with CIRA 1972 curves

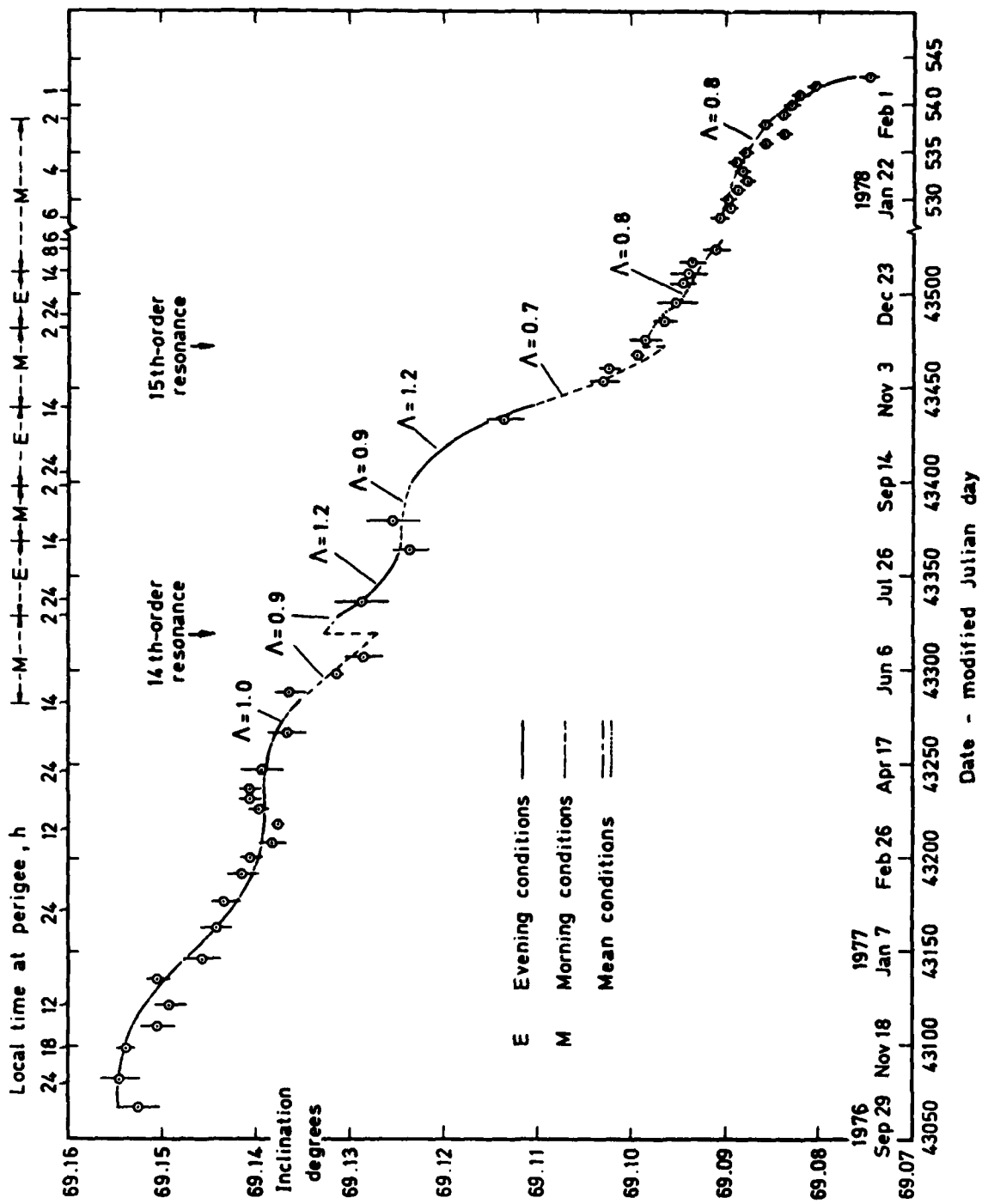


Fig 8

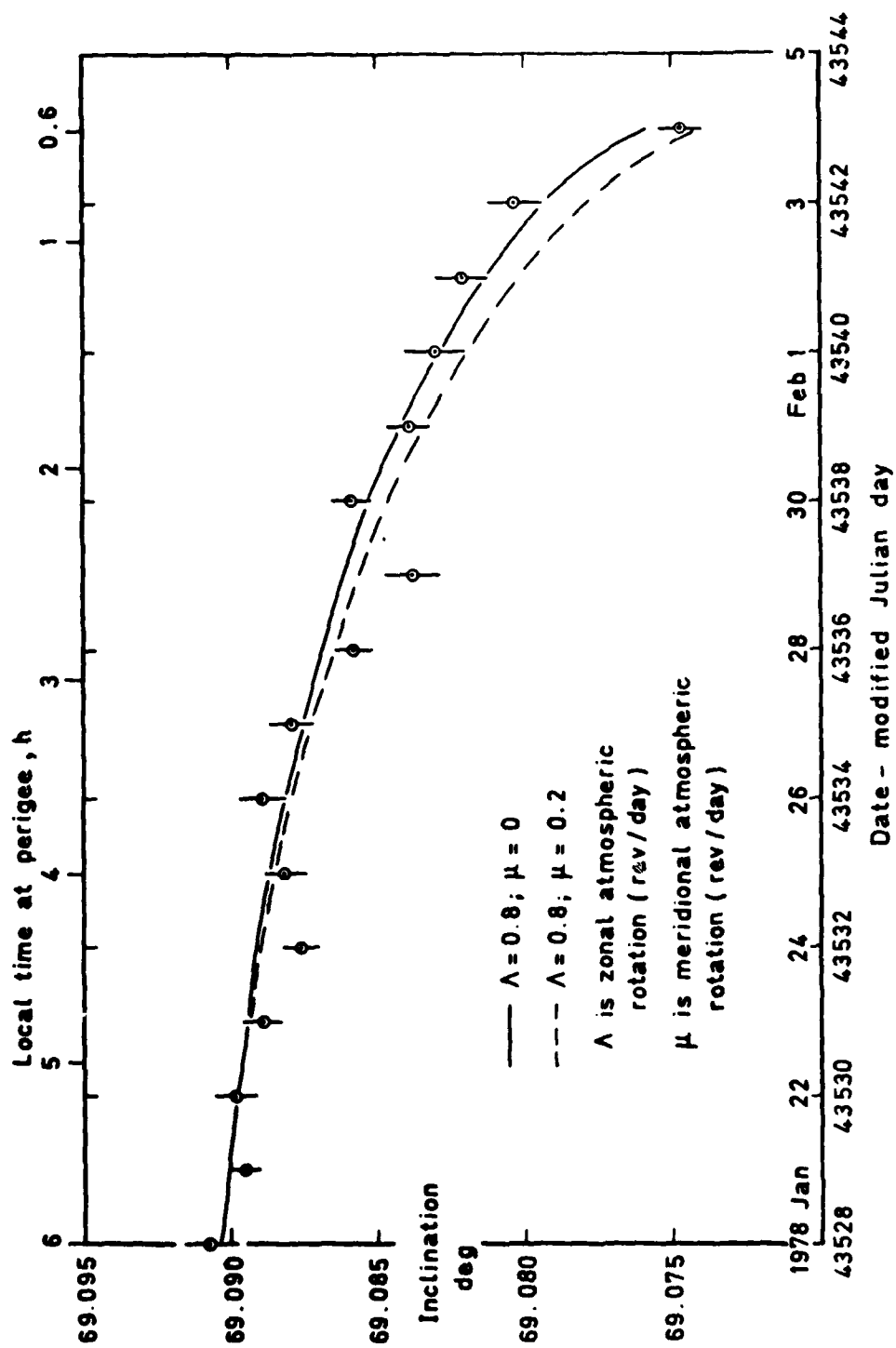


Fig 8 Perturbation-free inclination, with sd, and fitted rotation curves, near decay

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17. Abstract The orbit of China 6 rocket, 1976-87B, has been determined at 51 epochs during its 17-month life, using the RAE orbit refinement computer program, PROP 6, with over 4000 radar and optical observations from 49 stations. The orbital accuracy is about 100 metres, radial and cross-track. The rotation rate of the upper atmosphere, Λ rev/day, for the height-band 200-230 km, was calculated from the decrease in orbital inclination (after being cleared of perturbations) to give the following results: (1) Λ for morning conditions, $\Lambda = 0.9$ for May-June and August-September 1977, at 215 km mean height; $\Lambda = 0.7$ for October-November 1977, at 210 km; $\Lambda = 0.8 \pm 0.05$ for January-February 1978, at 200 km; (2) Λ for evening conditions, $\Lambda = 1.2$ for July and September-October 1977, at 215 km; (3) Λ for mean (morning plus evening) conditions, $\Lambda = 1.0 \pm 0.1$ between October 1976 and May 1977, at 230 km; $\Lambda = 0.8 \pm 0.1$ for December 1977-January 1978, at 215 km and mean latitude 57° S. Values of density scale height have been obtained from the variation in perigee height, including several values during the final 16 days to decay. Comparison with CIRA 1972 values shows agreement mostly within 10 per cent.					